Mechanisms of dehydration in the TTL

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Abstract: We use Aura MLS H_2O and O_3 measurements along with measurements of cloud occurrence from the Calipso lidar to gain insight into the mechanisms of cloud formation and dehydration. We see that regions of deep convection show the presence of clouds, and that these air masses are associated wth reduced H_2O vapor and O_3.

Motivation

Following the landmark work of Holton and Gettelman [2001], trajectory models of the TTL, such as the model of Fueglistaler et al. [2004, 2005], have shown that large-scale dehydration models can reproduce the observed H_2O entering the stratosphere. However, large-scale dehydration models have problems with other constituents, such as isotopes of water. Adding convection to the model can solve the isotope issue [Dessler et al., 2007].

We use new A-train data to further explore the validity of large-scale dehydration models. In particular, we analyze O_3, a constituent that should be affected by convection but does not condense. By looking at the simultaneous behavior of H_2O and O_3, we hope to gain insight into the impacts of in situ dehydration and convection on TTL dehydration.

Data

MLS: The Microwave Limb Sounder measures H_2O and O_3 mixing ratio at 100 hPa with ~3 km vertical resolution and 10-20% accuracy.

Calipso cloud lidar: This instrument measures cloud altitude and optical depth.

Onto each Calipso measurement we linearly interpolate the MLS H2O and O_3 measurement to the location of the Calipso measurement. The MLS and Calipso measurements are made just a few minutes apart in time, and there is offset of 100-200 km in longitude between the Calipso and MLS measurement tracks. In gridding the MLS data onto the Calipso data, we ignore the longitudinal offset.

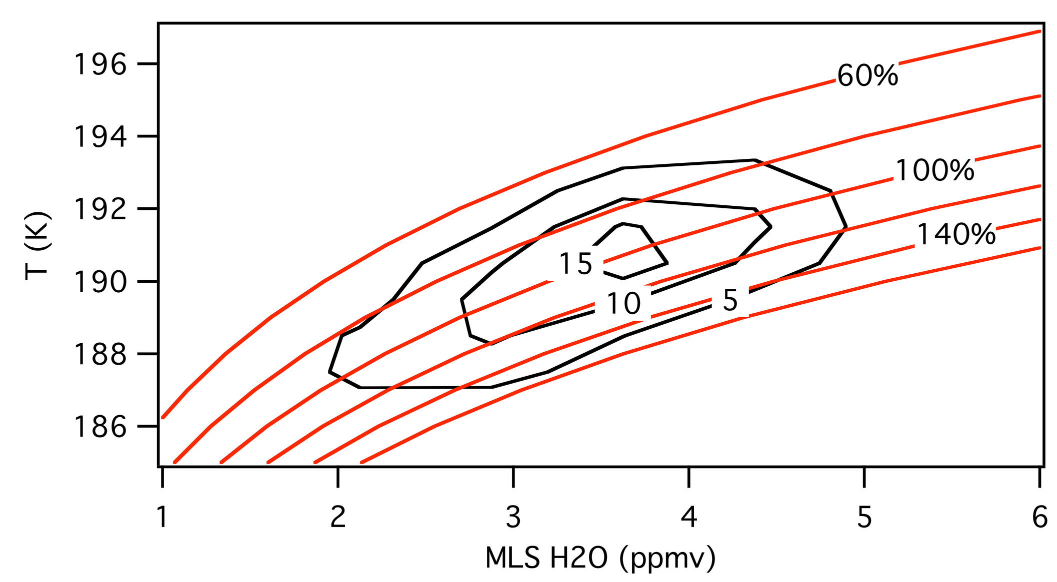
MODIS: The Moderate Resolution Imaging Spectroradiometer measures brightness temperatures at a range of visible and infrared wavelengths. We use here 1-km resolution measurements of 11-µm brightness temperature taken in a 100-km wide strip surrounding the Calipso track. We use the fraction of brightness temperatures less than 210 K as a proxy for deep, TTL-penetrating convection.

Time and location of analysis

All of the analysis here is done at 100 hPa, the standard pressure level closest to the tropopause.

We look at two time periods: December 2006-January 2007-February 2007, hereafter DJF, and June 2007-July 2007-August 2007, hereafter JJA.

Observations of clouds as a function of T and H_2O

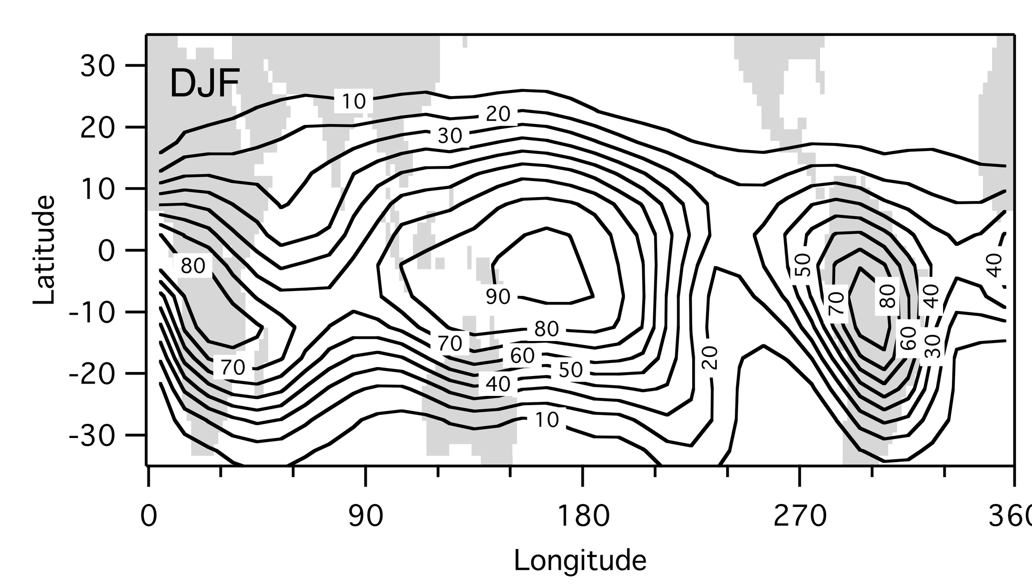


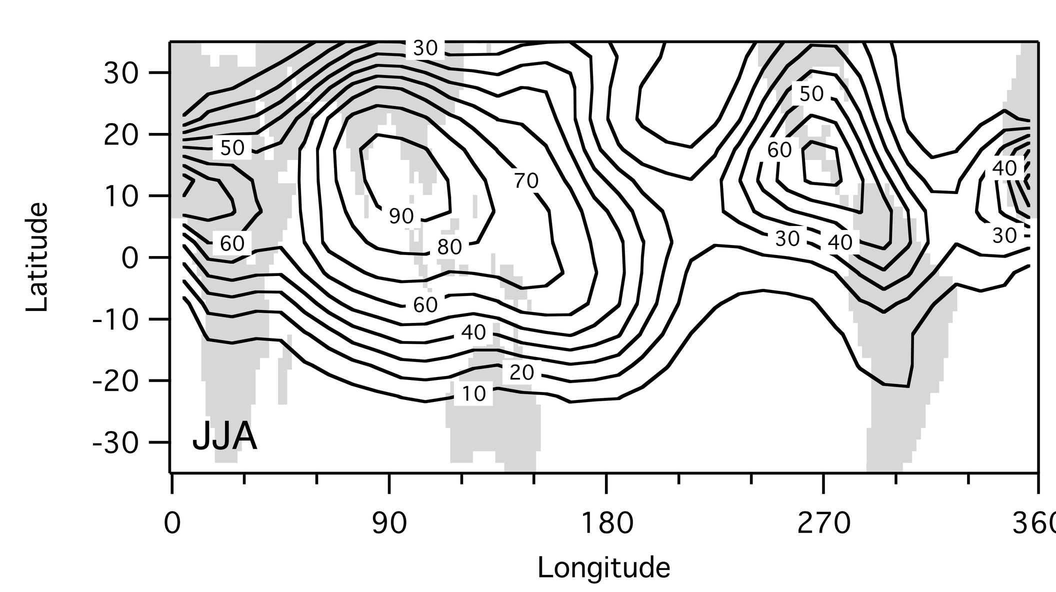
Black contours show the number (in thousands) of Calipso observations of cloud at 100 hPa as a function of H_2O mixing ratio and temperature, both at 100 hPa. The red lines are lines of constant RH. Data are from DJF.

This plot shows that clouds are predominantly occurring at RH = 100%, with virtually no clouds occurring at RH > 160%. Some clouds are seen in air with RH < 100%. We use this plot to verify our interpolation scheme and show that it produces reasonable results.

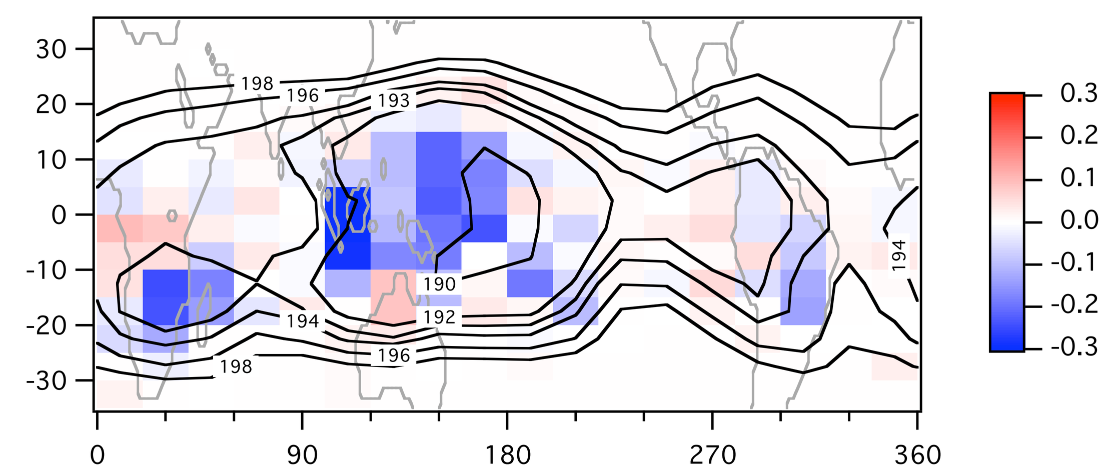
And, while not important for this analysis, this also provides strong evidence for the accurate calibration of the Aura MLS H2O measurement.

As context, below are location of clouds detected by Calipso with tops above 100 hPa in DJF and JJA. Note that in the convective centers, the cloud fraction is > 80%.



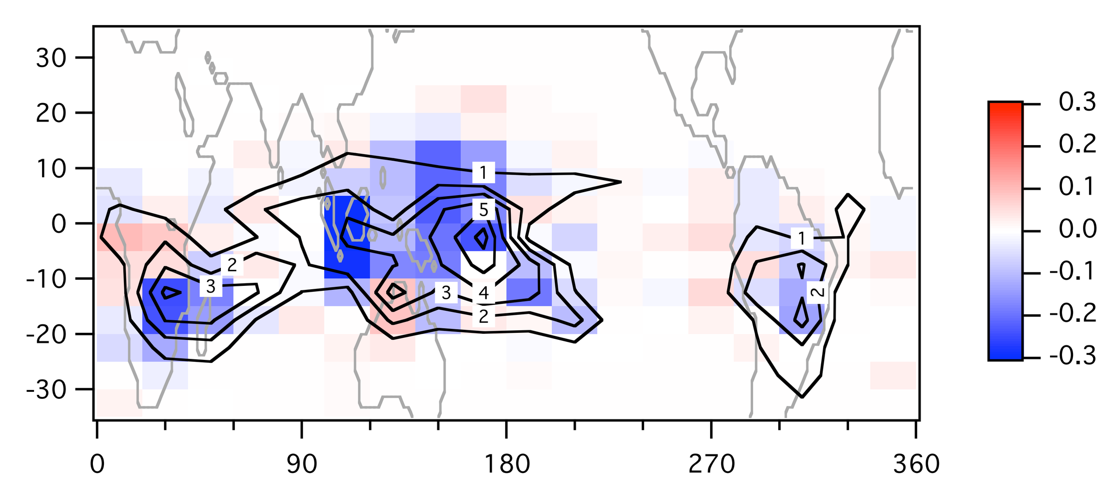


$[H_2O]-[H_2O]_{clear}$



The color plot above shows the difference between 100-hPa H_2O vapor and clear-sky (no cloud at 100 hPa) H_2O vapor for DJF in ppmv. Negative values indicate that H2O vapor is lower when clouds are present, while positive values indicate that H_2O is higher when clouds are present.

The contours are 100-hPa temperatures. Note that regions where the temperatures are lowest are not the same regions where you find the biggest difference between all-sky and clear H_2O. This provides no support for the simple large-scale dehydration models model of TTL dehydration.

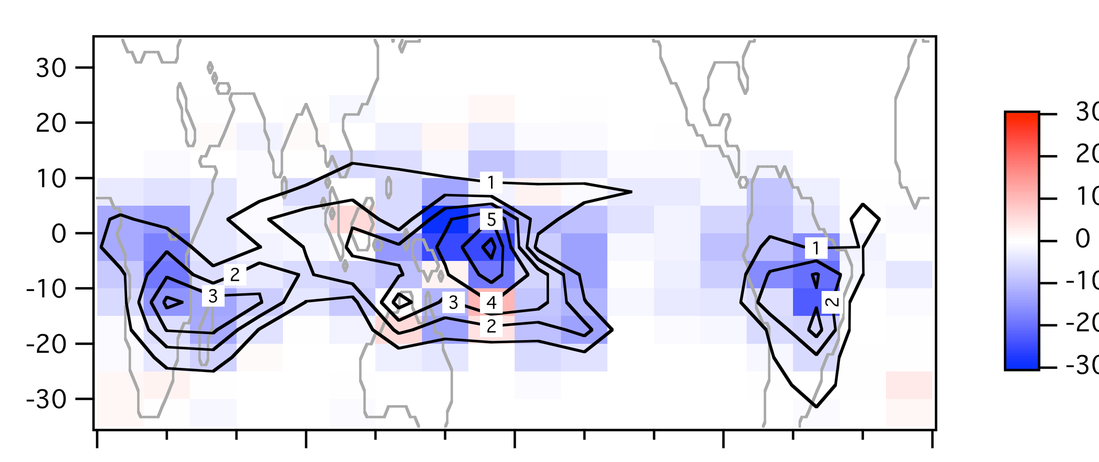


The color plot above is the same as in the previous figure. The contours, however, are the fraction (in %) of MODIS 11-µm brightness temperatures that are below 210 K for DJF. This is a proxy for convection that penetrates the TTL.

Note that the BT contours match the regions where H_2O is reduced in the presence of ice.

This suggests that convection is playing a more direct role in the process that is reducing H_2O in the presence of ice than large-scale temperature. This is basically the same conclusion as was reached by Dessler et al. [2006].

$[O_3]-[O_3]_{clear}$

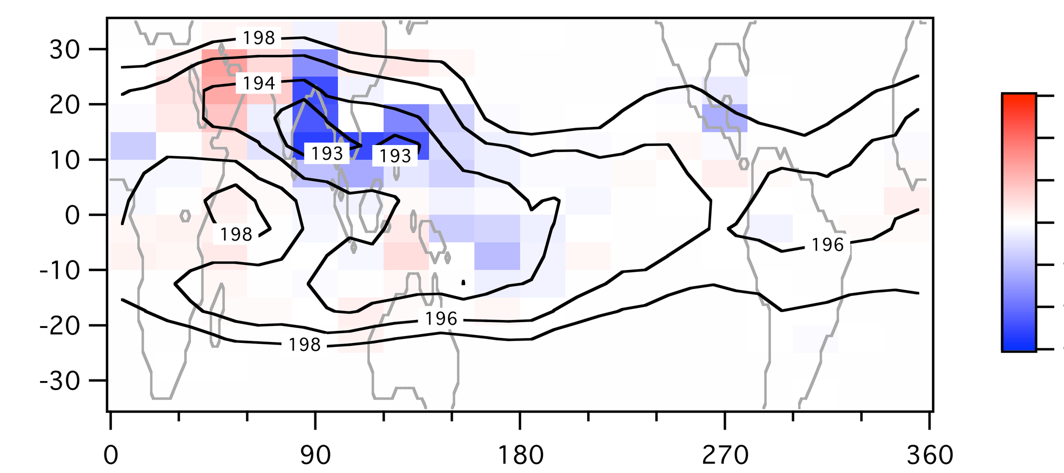


The color plot above shows the difference between 100-hPa O_3 and clear-sky (no cloud at 100 hPa) O_3 for DJF in ppbv. The contours are the fraction (in %) of MODIS 11-µm brightness temperatures that are below 210 K for DJF.

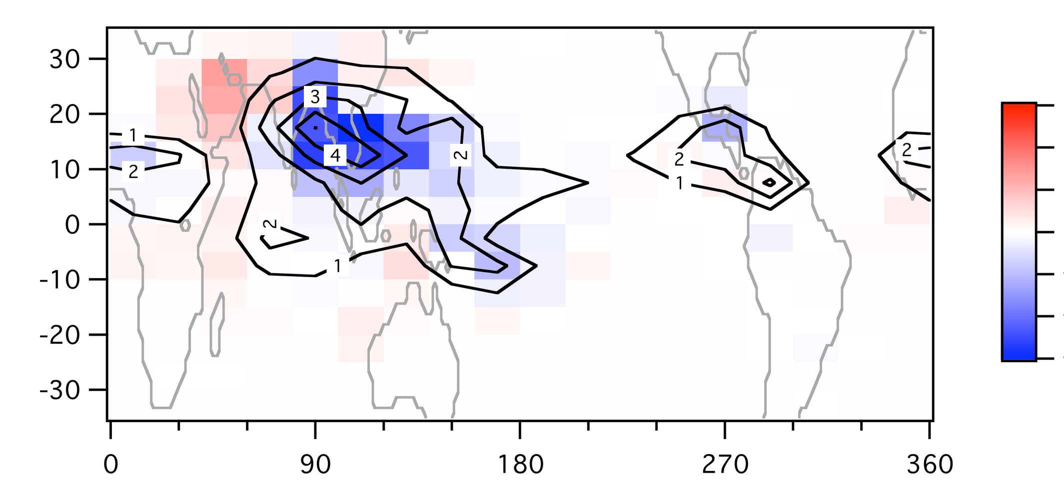
Note that O_3 in cloudy air is lower than O_3 in clear air in the same region. We note that O_3 is not lost through condensation the way that H_2O is. One possible interpretation is that O_3 is reduced because of detrainment of O_3-poor air. This hypothesis is consistent with the close coincidence between the low-O_3 regions and convection.

Changes in H_2O and O_3 in JJA

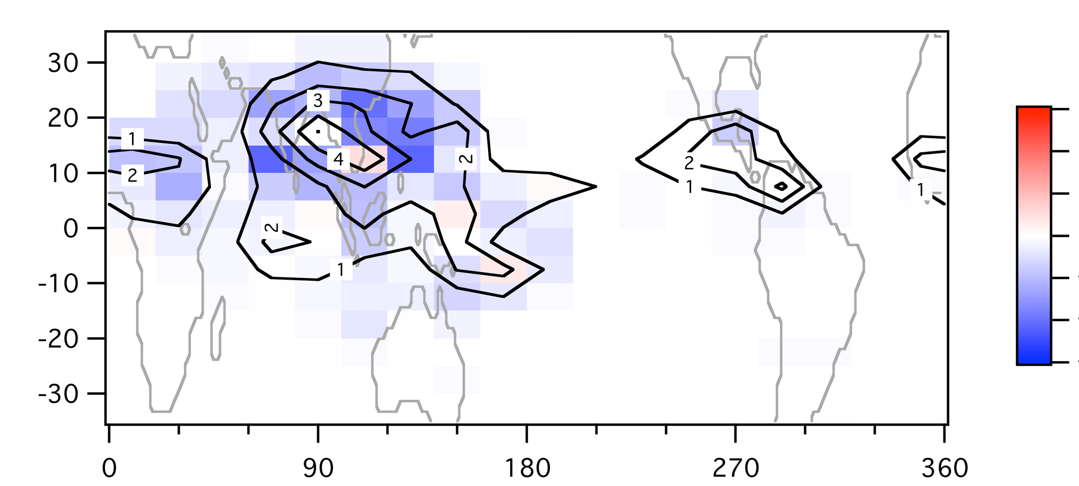
Difference between 100-hPa H_2O vapor and clear-sky (no cloud at 100 hPa) H_2O vapor for JJA in ppmv. Contours are 100-hPa temperature

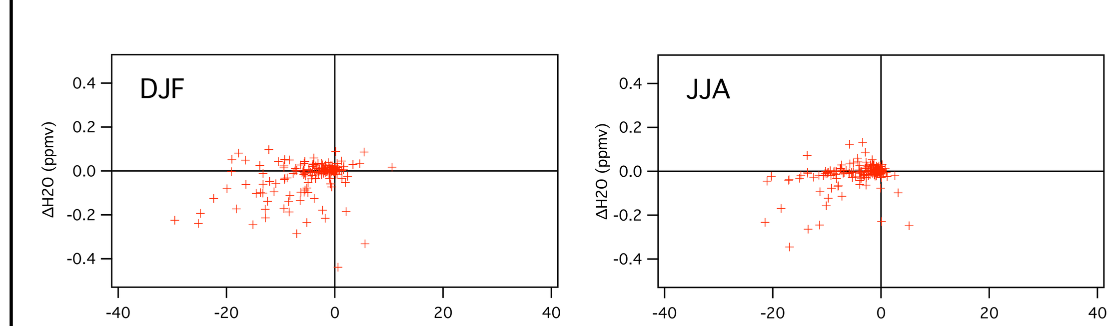


Difference between 100-hPa H_2O vapor and clear-sky (no cloud at 100 hPa) H_2O vapor for JJA in ppmv. Contours are BT < 210 K.



Difference between 100-hPa O_3 and clear-sky (no cloud at 100 hPa) O_3 for JJA in ppbv. Contours are BT < 210 K.





Decreases in H_2O in the presence of clouds is correlated with decreases in O_3. It seems unlikely that large-scale dehydration models would be able to reproduce that. Rather, as I have argued before, it appears that convection is playing some role in dehydration, although this analysis cannot isolate what that role is.